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Simulation and Testing of Induction Motors Used with Irrigation Pumps

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(**Abstract**) AC motors have gained wide ranging applications in the present day scenario. Adoption of innovatively designed speed control mechanisms in the industrial sector has revolutionized these drives. Now-a-days the industrial sector has a well organized power supply system, wherein motors used for specific industrial applications are not subjected to abrupt supply variations. Thus their operating conditions remain nearly the same throughout their life span. There are certain areas like the agricultural sector which use AC motors without any speed control mechanisms. In the agricultural sector, water pumps are used for irrigating small tracts of land from tube wells or open wells. Small and marginal farmers with lands along the banks of rivers have open wells even today with irrigation pumps. The three phase AC motors which are coupled to these pumps are subjected to a wide power supply voltage fluctuations depending on their distance from the distribution transformers. Supply voltages at motor terminals are never constant throughout the day and night. They are subjected to wide voltage fluctuations during different periods of the day and night. The most common problem faced by farmers is the burnout of motors. In order to ascertain the main reasons for burnout of motors used in irrigation pumps and observe their performance under variable supply voltage and load conditions, an experimental model was set up in the laboratory and relevant tests were carried out by simulating field conditions. It was observed from experimental results that with higher and lower values of supply voltage to the motor, the current drawn was higher and resulted in increased losses thereby creating higher thermal stresses. The basic idea of reducing losses could be achieved by using good quality core and conductor material for the motor, which would minimize thermal stresses. It could be finally summarized that an Energy efficient induction motor as per specific needs of the agricultural sector has to be designed and manufactured keeping the cost factor in mind.

Keywords: Simulation, Performance of Motors, Supply Voltage Variations, Induction Motors, Irrigation Pumps

1. INTRODUCTION

Agriculture is still a major occupation in India as majority of its population is concentrated in rural areas. Population explosion is creating a heavy demand for food grains in the country; hence, the role of farmers in improving the food grain situation of the country acquires prominence. It is therefore needless to say that farmers form the backbone of our country. A farmer therefore needs to be supported in all ways to provide maximum grain output with minimum efforts. Though the government has taken up many irrigation projects to provide canal irrigation, the coverage area is restricted due to geographical and economical reasons.

Earlier farmers used diesel engine coupled pumps for irrigation purposes; the mounting pressure of oil crisis forced them to use electric motors. Electricity being clean as well as economical became a dependable source of power for irrigation. As an incentive many state governments provide electricity at subsidized rates to farmers for their irrigation pumps. These pumps have helped farmers to a large extent in irrigating their farm lands. Electric motors used for pumps can provide years of trouble free service when properly selected, operated and maintained. Since induction motors are quite popular in this sector, it is quite important to carry out studies about the effects of power quality on the efficiency and reliability of induction motors.

In induction motors, both the stator and rotor have laminated cores and if the core material is judiciously chosen, iron losses can be greatly minimized. If high quality copper wire is used in the stator windings then copper losses will be minimum. Squirrel cage rotors have aluminum cast into the rotor slots for better performance.

Induction motors available in the market are tailor made as per requirements of industrial sector wherein the starting torque requirements are usually large. Induction motors used in agricultural sector require normal starting torque, which leads to considerable improvement in full load running performance of motor and offsets the extra cost of starting equipment.

The pump load usually varies between 60 – 100% and sustains over a longer period of time, hence induction motors with flat topped efficiency curves are recommended for varying loads with low iron losses. When quality core

material is used, it improves motor efficiency as well as power factor and reduces thermal stresses. It can be summarized that an induction motor as per specific needs of the agricultural sector has to be designed and manufactured keeping the cost factor in mind.

Power system unbalance is a common phenomenon in electrical grids especially in case of 11KV systems. If the voltage applied to the terminals of a three phase induction motor is unbalanced, the motor performance will be modified. The net shaft torque produced by the machine will be somewhat less than that produced by a balanced supply. Some ill effects due to unbalanced voltages are:

- The motor will take longer time to run up.
- Increases the thermal stress in the motor which leads to reduction in life.
- The net torque is reduced and if full load is still demanded, then the motor will be forced to operate at a higher slip, thus increasing the rotor losses and heat dissipation.
- The reduction in the peak torque reduces the ability of a motor to ride through dips and sags, thus affecting the stability of the entire system.
- The percentage increase in temperature rise will be approximately twice the square of the percentage voltage unbalance.

As per experimental studies carried out, even a small voltage unbalance will result in large current unbalance during the running of motor by a factor of 6 times. During unbalance the negative phase sequence components will lead to heating of motor as well as reduction in motor output torque. The motor is forced to run at higher slip leading to increased rotor loss and reduced efficiency. Electricity boards should look in to this phenomenon seriously where irrigation pumps suffer voltage imbalance and even 1% loss of efficiency for a country like India would amount to great losses.

A variation in supply voltage of a motor coupled to a pump affects its speed. Pump performance gets altered when ever motor speed changes. Constant supply voltages applied to electric motors allow them to operate at a constant speed and makes them unable to match pump performances working under variable operating conditions and therefore the pump output is usually reduced or throttled. Variable-frequency drives of electric motors have the potential to adjust pump performance to match operating conditions by reducing motor and pump speed. They can save energy by reducing the horsepower demand of irrigation pumps. The annual energy saving is the difference in energy cost between the constant speed operation and the reduced speed operation. This difference depends on the amount of decrease in horsepower, the operating time at the reduced speed and the electricity costs. But the initial cost of the system would be high.

Electric motors used by farmers for their pumps, face frequent burnouts. The unbalanced supply voltage to the electric motors can cause severe thermal stresses in the motor and in due course of time result in the burnouts. This study is aimed at trying to determine specific reasons for motor burnouts and provide a solution to safeguard the financial interests of the farmers.

2. FIELD SURVEY

An exhaustive survey was conducted along the banks of river Krishna in Karnataka, to gather information regarding the following factors:

- Delivery head against which a pump had to operate during different seasons.
- Supply voltage availability at the location of pump belonging to the farmer.
- Technical specifications of the motor coupled to the pump.

Delivery head was found to be varying between 12 to 18 meters during summer and 6 to 10 meters during remaining part of the year.

The measured supply voltages were as low as 300 V early in the morning and in the evening and voltages as high as 475 V were measured during afternoons and late nights.

Most of the farmers used 5 HP motors while a few of them used 7.5 HP motors.

Motors used were mostly of Kirloskar make and many of them were rewound motors.

3. EXPERIMENTAL SET UP DETAILS

3.1. Equipment Used

Some of the popularly used motors were selected to study their performances:

- Kirloskar New- 3 phase, 5 HP, SCIM, 4 pole, 415 volts, 50 Hz, 7.6 amp, 1430 rpm, Delta connected, Class B insulation.
- Kirloskar Energy efficient- 3 phase, 5 HP, SCIM, 4 pole, 415 volts, 50 Hz, 7 amp, 1430 rpm, Delta connected, Class B insulation.
- Kirloskar Rewound - 3 phase, 5 HP, SCIM, 4 pole, 415 volts, 50 Hz, 7.6 amp, 1430 rpm, Delta connected, Class B insulation.

A centrifugal pump of DPF make, size 2” x 2”, speed 1440 rpm was coupled to the motor.

A valve attached on outlet side of pump was used to vary the delivery head against which the pump would have to work. The readings of pressure gauges on the inlet and outlet side of the pump together would give value of total head against which the pump had to work.

Water discharged by the pump was measured by allowing it to collect in a steel tank of size 80 cm x 80 cm x 80 cm.

A three phase auto-transformer was used to vary the input supply voltage.

Measuring instruments were used for measuring voltage, current and power. A digital tachometer was used to measure the motor speed.

3.2. Parameters Considered

The field survey results helped us in fixing parameters for simulating field conditions inside the laboratory as stated below:

- Delivery heads: 10, 13.5, 15.5 and 18.5 meters.

- Supply voltages: 300, 360, 415 and 475 volts.
- Rating of motor: 5 HP, 3ph Squirrel cage Induction motor.

3.3. Tests Conducted

The following tests were conducted to compare practically evaluated values with the theoretically obtained values, so that the motor performance could be established theoretically.

- Performance test on pump - Delivery head constant with varying supply voltage.
- Performance test on pump - Supply voltage constant with varying delivery head.
- No load and Blocked rotor test.
- Heat run test.

3.4. Measurement and Calculation of Different Parameters

Important parameters of interest were measured after conducting different tests and also calculated from test results.

- From performance test - Total head, Amount of water discharged, Input voltage, Input power, Input current and Motor speed were measured.
- From the Blocked rotor test readings - Effective resistance per phase of the motor was calculated.
- From No load test readings - Core loss in the motor at different voltages was calculated.
- The value of current drawn at different voltages and heads known - Copper loss in the windings was calculated. The sum of core loss and copper loss together yielded the value of total losses in the motor.
- Output of motor was obtained from the values of Motor input and total losses.
- Torque at different voltages and heads was calculated from output power of motor.

4. RESULT OF TESTS CONDUCTED

4.1. Performance Test - Delivery Head Maintained Constant with Variable Supply Voltage

The condition of constant delivery head with varying supply voltage is experienced practically by a pump under field conditions. This condition helps in observing the performance of a pump under practical situation. Further the role of a motor in the functioning of pump can be critically observed. The observations made were as follows-

- With increase in delivery head, the parameters Current, % Slip and motor losses decreased.
- With increase in delivery head, parameters like Energy consumed, Pump efficiency and Overall efficiency increased.
- Parameters like Input power, Power factor and Torque initially increased with increase in head but on further increase in head they decreased.
- Reactive power was low at 13.5 and 15.5 meters head, but high at 10 and 18.5 meters head.
- Water discharge was maximum at 13.5 meters head but low at other values of head.
- Motor efficiency was maximum at 15.5 meters and low at other values of head.

4.2. Performance Test - Supply Voltage Maintained Constant with Varying Delivery Head

The condition of constant supply voltage under varying delivery heads are rarely experienced by a pump in the field. This condition only helps in observing the performance of pump from the theoretical point of view. The motor performance under such a condition may be observed to analyze the results obtained. The observations made were as follows-

- With increase in voltage, the Power factor and % Slip decreased.
- With increase in voltage, the Input power and Reactive power increased.
- As voltage increased current decreased, but beyond rated voltage, the current increased.
- Motor losses and Energy consumption were minimum at rated voltages.
- Water discharge, Torque, Motor efficiency, Pump efficiency and Overall efficiency were maximum at rated as well as near rated voltage but reduced at lower and higher values of supply voltages.

4.3. Heat Run Test

The heat run test was conducted for a constant head of 13.50 meters at voltages of 300, 415 and 475 volts. The results proved that the temperature at rated voltage of 415 volts was very low, at higher voltage of 475 volts it was medium but at lower voltage of 300 volts it was very high. The reason for this increase in temperature at low voltages is attributed to the high current drawn in spite of lower core losses. Motors with higher effective resistance and higher core loss attain higher temperatures.

4.4. No-Load and Blocked Rotor Test

The No-load test was conducted at different voltages and the Core losses were found to be varying. As the supply voltage to the motor was increased the core losses increased. The magnetizing reactance and core loss resistance values were calculated. The blocked rotor test was conducted at rated current and also at a value little less than the rated current. The stator winding resistance was measured by DC test. After calculations, the average values of stator resistance and reactance as well as rotor resistance and reactance were obtained.

5. ANALYSIS

5.1. Approximate Analysis for Prediction of Motor Performance

In order to predict performance of motor with pump load at different voltages, following assumptions were made:

- In order to decide motor characteristics, core losses were neglected.
- Frictional torque was neglected.
- Pump used was assumed to be ideal and working under ideal conditions.

5.2. Motor Characteristics

In order to obtain torque-speed characteristics of the motor, the Theremin's equivalent circuit was considered. The developed torque at different supply voltages was calculated. Observations made about motor parameters and other quantities are listed below:

- Effective resistance per phase of energy efficient motor was found to have lower values while the rewound motor had higher values.
- Reactance per phase of rewound motor was found to have lower values while that of energy efficient motor had higher values.
- Magnetizing reactance of rewound motor was found to have lower values while that of energy efficient motor had higher values.
- Core loss in an energy efficient motor was found to be low while that of a rewound motor was found to be high.

5.3. Load Characteristics of Pump

Load characteristic of a pump is dependent on the torque demanded by it at different speeds for a particular value of delivery head. The demanded torque at any speed being a known value, the pump constants were calculated for different delivery heads at rated motor supply voltage. Load torque for different pump constants at different per unit speeds was also calculated. When demanded torque is equal to load torque, the motor will operate at a steady speed if frictional torque is neglected.

We have, Per unit speed = (1-Slip), so the value of slip will help us in evaluating the performance characteristics of a motor using its equivalent circuit.

The intersecting point of the motor characteristics and the pump characteristics yields the stable operating point for any supply voltage and any pump constant. Thus the value of slip or per unit speed obtained is used for further analysis.

The operating speeds at rated voltage of 415 volts for different pump constants was calculated from the graph (**Figure-1**) and compared with the measured values.

6. DISCUSSIONS

The effect of voltage fluctuation on an irrigation pump was studied by conducting various tests in the laboratory by simulating field conditions. An approximate analysis for predicting the behavior of a pump with the knowledge of its parameters was also carried out. It was evident that normal equivalent circuit of induction motor could be used to determine the motor characteristics.

The pump characteristics were determined accurately by assuming the demanded load torque to be proportional to the square of the speed for a particular delivery head. The intersecting point of motor and pump characteristics would decide operating speed of pump at any given voltage. **Table-1** shows close agreement between the practically measured and theoretically calculated values of motor speed indicating that this approximate analysis could be adopted for predicting pump performance. The pump constant can be calculated using the value of torque obtained from performance test of pump. Thus by knowing pump constant and motor parameters, effect of voltage fluctuation on performance of pump could be studied. It would be necessary to be cautious while choosing value of magnetizing reactance X_m and core loss during calculations as these parameters vary with supply voltage.

At higher values of supply voltage power factor decreased, this was possible due to magnetic saturation and fall in value of magnetizing reactance. At higher voltages, though slip was very low, current drawn by motor was high due to increasing value of magnetizing current. The core loss was observed to be high; hence total losses would increase resulting in higher temperatures.

At lower supply voltage, current drawn by motor was high due to higher values of slip. Though core loss was observed to be low, copper loss was high due to higher current drawn by motor. Hence, it could be concluded that heating was primarily decided by magnitude of electrical losses in motor. The power factor was observed to be high due to low air gap flux density in the unsaturated region and due to higher value of magnetizing reactance.

The motor temperature was observed to be high at lower as well as higher supply voltages.

7. CONCLUSIONS

After going through the results, use of energy efficient or rewound motors was found to be advantageous. Taking the cost factor into consideration, a rewound motor was found to be cheaper and effective. The rewound motor because of its debated design is found to be ideal for irrigation purposes. In order to prevent motor overheating due to unbalanced voltages, the motor has to be operated below its rated output power which is known as debating of the induction motor. Premature failure can only be prevented by debating of the machine to allow it to operate within the thermal limitations.

The suggestions for a farmer using pumps for irrigation purposes are to incorporate a single phase preventer and a thermal relay. A single phase preventer would trip the power supply to the motor when one of the phase fails. A thermal relay would trip power supply to the motor when temperature of stator winding reaches a designated value which could deteriorate its insulation. These protective devices may extend motor life but they may be inappropriate for pumping systems where irrigating the crops is more critical than reduction of motor life.

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Table 1. Calculated as well as measured values of speed at rated voltage of 415 V and different delivery heads.

Sl. No.	Delivery heads of								Make of Motor
	10.00 meters		13.50 meters		15.50 meters		18.50 meters		
	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	
1	1435	1440	1429	1435	1430	1436	1440	1444	**Kirloskar- New**
2	1437	1444	1431	1440	1431	1439	1445	1451	**Kirloskar- Energy Effecient**
3	1431	1436	1426	1433	1424	1432	1432	1440	**Kirloskar- Rewound**

Figure 1. Graph of Developed Torque Vs Slip of motor and Load Torque Vs Per unit Speed of pump.